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Russo S., Salvalato I.

in

Chataigner J. (ed.).
Future of water management for rice in Mediterranean climate areas: Proceedings of the Workshops

Montpellier : CIHEAM
Cahiers Options Méditerranéennes; n. 40

1999
pages 47-60

Performance of rice cultivars in experimental trials with dry method of cultivation

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Abstract. Field experiment was carried out in the period 1994-1997 on a Vercelli sandy-loam soil to evaluate the performance of 15 rice genotypes under no flooded water regime. Irrigation applications by flushing method were generally three through the cultivation season. Total water applied was 800-900 m^3 per hectare following the season. Rainfall during different years totalled 3000-4000 m^3 per hectare and season and was normally well distributed. Total water supply (rainfall plus irrigation) was calculated as about 3800-6600 m^3 per hectare following the season, during a period standard of 150 days. Plant height, days to heading and ripening, yield and milling yield were measured. No flooded aerobic culture influenced growth and cycle duration of different genotypes. Commercial indica and japonica type, Panda, Koral, Pegaso, Dorella, Loto, Ghibli and other selecting lines performed well in similar dry soil conditions. Several genotypes showed yield losses due essentially to increased floret sterility and reduced filled grain. Earlier maturing varieties would appear to be more adapted to the aerobic irrigated culture. Earliness showed to be in some extent related to the water stress tolerance.

Pot experiments in lysimeters were also also carried out on a Vercelli sandy-loam soil to evaluate the comparative effect of flooded and dry cultivation methods, combined with different rates of N, on rice crop (Oryza sativa, L.). Water regimes were continuously flooded and periodically irrigated by sprinkler method to maintain about 20% of soil moisture. The nitrogen treatments in factorial combination with water regime were 100, 150 and 200 kg urea-N ha^{-1}, each applied in three equal split doses before transplanting, at middle tillering ad panicle initiation stage, respectively. Growth and yield parameters were recorded to determine the fate of applied N fertilizer and the effect on rice crop. Dry cultivation, compared with flooded condition, significantly increased soil extractable NH4 and NO3 which accumulated after the first and second application of N fertilizer. Total and protein-N concentrations significantly increased in dry regime treatments at increasing rates of urea-N application. On an overall basis, this research has demonstrated that reduced yield and N uptake by rice plants in dry conditions could be depending on the larger process of nitrification in the dry soil followed by higher rates of N leaching.

Introduction

Cultural methods for rice (Oryza sativa, L.) production in the world include both flooded and upland with large predominancy of flooded rice culture in temperate areas (such as is practised in the European continent).

The flood is generally used as a management tool, not a specific requirement of the rice plant Permanent flooding conditions during the crop growth provide a continuous and adequate supply of water, a better control of the nonaquatic weeds, facilitate the use of granular insecticides and herbicides, reduce losses of ammonium fertilizer, and enhance availability of nutrients such as phosphorus, iron, manganese following reduction of the soil due to the exclusion of oxygen by the flood water (SHAPIRO, 1958; PONNAMPERUMA, 1965; PATRICK et al., 1985).

However, this system requires large water amounts and may increase the difficulty and cost of applying pesticides and fertilizer and using special machinery for ricefield. Generally, the conventional flooding technique is very high water consuming (15,000-18,000 m^3 for hectare in the Italian ricefield conditions). BROWN et al. (1978) have indicated that 48% (570 mm) of the applied irrigation water (1180 mm) was lost through evapotranspiration (ET). The remainder was lost due to runoff and infiltration. Water in the conventional rice crop represents therefore a major and necessary production cost for the growers.

On the other hand, often rice producers have to face increasing competitive uses of water. Moreover, very often the water quality is getting worse due to the chemical pollution.

With the traditional rice system, under temperate conditions (including the Italian), the direct water broadcast sowing method couldn't be able to prevent some damaging effects of adverse environmental conditions on the plantlet establishment.

It is necessary to considerate that normally the main constraints affecting rice growing under temperate conditions at the initial stage are:

- ❏ cold damage;
- ❏ wind effect (it may hamper or slow the rice establishment);
- ❏ crustaceans and worms activity in submerged soil;
- ❏ algae populations development;
- ❏ strong competition of aquatic weeds (such as the Heterathera, spp.);
- ❏ water shortage.

Alternative methods of planting by drilling or aerobic cultivation (dry rice) are ideal in order to prevent these damaging effects and save water. DEDATTA (1975) indicates that rice is grown under upland conditions on three continents of the world. Upland cultural system uses only rainfall. Upland production occurs in areas where the rainfall seldom, or never, causes flooded conditions.

Upland yields of more then 7 t. ha^{-1} have been recorded, indicating that rice doesn't require flooded conditions for high yields (DEDATTA, 1975). To do so, different methods can be used.

Initial research indicates sprinkler irrigation as an alternate method of irrigation. Sprinkler irrigation can contribute substantially to lower water consumption.

An efficient system based on the sprinkler irrigation, in order to prevent plant stress in the critical periods, should sustain optimum rice yields. However, reports from several areas have shown highly variable results (FERGUSON and GILMOUR, 1977, 1978; WESTCOTT and VINES, 1986; McCAULEY, 1990). Following these results, further research to compare the effects of normal flood irrigation and sprinkler or other suitable irrigation system on rice yield and quality is requested.

Alternative method of growing rice like aerobic cultivation is important in order to reduce the cost of rice production and save water. Preliminary studies in Italian climatic environments have shown promising results when rice was grown under dryland conditions, using sprinkler or flushing irrigation rather than flooding, indicating that rice does not necessary require flooded conditions for high yield and good grain quality (LOSAVIO at al., 1997; RUSSO and NARDI, 1996).

Dynamic aspects of nutrient uptake have also to be considered in dryland conditions, with special regard to the nitrogen, in order to optimize the yielding response of rice, as compared to the flooded.

In order to develop new promising varieties and more efficient rice cultural practices, particularly water and nutrient management, field and lysimetric experiments were carried out with dry rice. The objective was to study the rice response in dry conditions and the best method for nitrogen application.

I – Field experiments

1. Materials and methods

The objective of this study was to evaluate the response of several rice cultivars and new selected lines to dry cultivation with flushing irrigation method applied in the groundwater-irrigated area of northern Italy (Po Valley).

Experiments were carried-out in the period 1994-1997 on a loam-sandy soil in the experimental field of the Sezione Specializzata per la Risicoltura, at Vercelli, to detect the performance of major commercial rice cultivars and new lines in dryland conditions with minimal irrigation by flushing. The compared genotypes included common round, medium and long grain cultivars and lines developed in Italy under conventional flooded culture.

The experiment plan was a complete randomized block design with four replications for each of the 15 genotypes compared. Plots were 10 x 1,5 m sized, separated 0,6 m and consisted of eight rows 0,18 m apart. Rice varieties were seeded on end of April or first of May depending from the season. The method of sowing was drilling at 2 cm deep on a completely dry soil. This method gave uniform seedling emergence for all the plots in a 10-13 days. Generally not supplementary irrigation was requested for the germination and emergence of rice seedlings. Except for the 1997 where a very long dry season made necessary the application of a initial irrigation to promote the rice germination.

The water for irrigation was supplied by flushing method from a gravity-feed irrigation system.

The irrigation treatments through the cultural season were designed so that rainfall plus irrigation were enough to maintain about 20 % of soil moisture and assure no damaging effect from water stress. The irrigation treatments consisted of periodical shallow flood with which soil was flooded during only a night by flushing. Irrigation was resorted to when the soil moisture dropped to 18-19%. Following the season and depending from the adequate rainfall, two or three seasonal water treatments were in all necessary in each year in this experimental field.

Standard cultural procedures were adopted. For the fertilization phosphorus (60 kg P_2O_5 ha^{-1}) and potassium (105 kg K_2O ha^{-1}) were applied as recommended before planting. Nitrogen was applied as urea in four separate applications: the first application was made preplant and incorporated with straw by ploughing. The successive applications were made by hand broadcast just after emergence, at late tillering and panicle differentiation stages. The total applied nitrogen amount was 170 kg/ha, about 25% more than standard used in normal flooded culture.

Weeds were controlled chemically as required by replicated (two or three) applications of standard rice herbicides mixture (Propanil + Bensulfuron methyl).

Recorded observations included heading date, plant height at harvesting, and ripening date. All plots were harvested mechanically by plot combine. The grain was dried, cleaned and weighed. Yields were calculated on the basis of 14% moisture. An adequate grain sample was collected from each yield plot to determine head rice yield (percent of whole milled grain).

2. Results and discussion

Total water applied by irrigation was 800-900 m^3 per hectare following the season. Rainfall during different years was adequate and normally well distributed as totalled 5380 m^3 in the 1994 experiment, 5690 m^3 in 1995, 3580 m^3 in 1996 , and 2920 m^3 in 1997 per hectare and per seasonal period standard of 150 days. Total water supply (rainfall plus irrigation) was calculated as 3820-6590 m^3 per hectare following the season.

These rates are very low compared with the water normally applied to a conventional flooded culture, consuming about 13-15000 m^3 in this rice area. However, we have to consider the favourable climatic conditions (high air relative humidity, with very low windiness, in the growing season) in the Po Valley (Northern Italy).This area is moreover characterized by quite superficial underground water table (about 0,6 m in dry soils) which, with all probability, influences the rice growth.

A. Growth and development

Non-flooded aerobic regime influenced in some extent the growth and cycle duration of different rice genotypes.

Non-flooded conditions practically had no effect on seedling emergence. However, after this stage rice development was slightly affected by stresses from inadequate water supply and soil moisture.

Growth and development of rices were apparently normal, except the production of biomass that resulted slightly reduced as showed from plant height lower than conventional culture. Moreover, rices showed more reduced and superficial roots due to the water stress in the upper layers of soil.

All varieties showed longer cycle duration but reached the complete ripening except a line derived from Inta x Panda cross.

Generally, earlier varieties were good performing and showed to be more adapted to the dry conditions. Earliness may be thus used as a suitable criterion for selecting new more tolerant varieties.

B. Heading date

Heading dates were recorded in all plots and the average values of time to heading (Table 1) are expressed as the number of days from seeding (DS) for each cultivar. The indica type variety Ghibli (96 to 103 DS) and Inta x Panda selecting line (130 DS), as well as the cultivar Perla (138 DS) headed among the first and last, respectively, indicating that stresses from non-flooded conditions, which may be occurred, influenced remarkably the cycle from sowing to heading in relation to the genotypes. In general, aerobic cultivation resulted in a delay in heading time. Cultivars with early or medium time to heading performed generally better.

C. Ripening

Ripening dates based on morphological observations were also recorded and expressed as the number of days from seeding (DS). Moreover, percentage of grain moisture content gives better information about the ripening time and more suitable harvesting date.

Generally, cycle duration to ripening was affected more than time to heading in relation to different cultivars (Table 2). Several genotypes showing low grain moisture content at harvesting time performed very well (Fig. 1). The top-yielding varieties Koral and Panda provided good maturing features in four years and were among the earliest genotypes. The earliest variety through the experiment period was Ghibli (135 DS), also good performing. Very long duration varieties showed significant yield reduction compared with the top-yielding variety, indicating poor adaptability to the dry conditions. The rices Dedalo, Drago, Giada and Graldo resulted the latest varieties at maturity (> 17o DS) and poorly performing. In spite of the effect of water stress the most performing rices generally showed a low incidence of floret sterility through the various years.

Other genotypes like UPLA 64C x 237 and Diana gave very high yields but in a single year (1997).

D. Rice yield

Average rice yields (at 14% of moisture content) for the various cultivars are shown in Table 3. Due to the water shortening treatment several genotypes exhibited yield losses indicating insufficient adaptability to non flooded culture. But some cultivars performed very well in similar dry conditions. The rice Panda, a commercial indica type, developed for its long grain (Long B) and Koral rice were the top-yielding cultivars through the crop seasons and produced (about 6 t/ha) very close with the standard culture. They appear to be good tolerant to water stress in dry conditions. Other long grain rices such as Ghibli, Pegaso, Dorella UPLA 64A performed also well under dry conditions. Medium grain Loto, Drago, Selenio, Perla very high yielding cultivars with traditional flood irrigation and long grain cultivars Graldo, Giada, showed significant yield reduction under dry conditions following the season, compared with the top-yielding varieties. Selecting line from Inta x Panda cross appeared to be extremely sensitive to water stress. Its' yield was very low under dry conditions due essentially to high floret sterility, not complete grain filling and very long cycle duration.

Generally in this experiment the yielding response of genotypes vas related to the earliest maturing capacity as indicated from moisture content in the mature grain. Fig.1 shows this relation for the year 1994. Similar trend was observed for the other years in the diagram plotting the grain moisture content at ripening stage and yield responses. Earlier maturing varieties would appear to be more adapted to the aerobic irrigated culture. Earliness showed to be in some extent related to the water stress tolerance and it can be considered as a important physiological aspect involved with the breeding procedures for drought tolerance.

In the 1994 season was evaluated also the effect of dry cultivation on the qualitative traits of the rice grain, including protein and amylose content, time of starch gelatinization (as a test for the rice cooking time) and milling head yield. The results of this research showed that the dry method of cultivation not changed substantially these very important commercial and qualitative characteristics. In some cases the dry method even improved the grain quality (Fig. 2-4).

II – Lysimetric experiments

1. Materials and methods

A pot experiment in lysimetric boxes with 4 replications was conducted in 1996 on a loam-sandy soil at the Sezione Specializzata per la Risicoltura, at Vercelli (Italy). For the experiment was used a loam-sandy soil colleted from the plough layers of a paddy field and packed in the lysimetric pots. The soil contained 0.12 % total N, 2.2 % organic matter, 11.5 meq 100 g-1 cation exchange capacity, 0.48 % exchangeable K, 0.041 % total P and a pH of 6.8.

The experiment had a factorial design with 4 replications and the following treatments:

- ❏ Cultural methods. Flooded conditions maintaining standing floodwater to approximately 5 cm depth and non-flooded condition (dry culture) with periodical irrigations by sprinkler method;
- ❏ Levels of N were: N-100 (N1), 150 (N2), and 200 (N3) kg N ha^{-1} as urea applied in three equal split doses.

The first N dose was broadcast basically in both cultural methods on dry soil. The second and third doses were topdressed at 4 and 9 weeks after transplanting, at tillering and panicle initiation stage, respectively.

All treatments received a basal application of 40 kg P2O5 ha^{-1} as Thomas sludge and 200 kg K2O ha^{-1} as KCl.

Rice (Oryza sativa L.) seedlings were transplanted on May 31 in both cultural methods on wet soil and immediately after, lysimeters with with the flooded treatments were submerged. The irrigation treatments in non-flooded lysimeters were designed so that rainfall plus water supply were enough to maintain about 20 % of the soil moisture.

During the crop cycle the recorded observations on rice plants included heading date, plant height at different stages and ripening date. Rice was harvested at maturity on October 29 and paddy yield was expressed on the 14 % moisture basis. An adequate grain sample was taken each lysimeter to determine head rice yield (milling rate) as a percentage of the whole grain.

Grain was analysed for total N, protein N and NO3-N contents.

2. Results and discussion

The total rainfall amount during the 1996 growing season reached 2600 m^3 per hectare and was well distributed. Total water (rainfall plus water supply) applied to the non-flooded lysimeters (dry conditions) was calculated as about 5200 m^3 per hectare. This amount was very low compared with the water applied to a conventional flooded culture consuming about 13-15000 m^3 in this rice area.

A.Plant growth study and rice yield

a] Plant height

Changes in plant height as one of the parameters of plant growth are shown in Table 4. The plant height recorded from middle tillering stage in all the treatments increased up to maturity with a range between 78.85 and 109.67 cm. The highest value (109.67 cm) at harvesting time was observed in N3 flood treatment and the lowest (78.85 cm) in N2 dry culture. There were significant differences in the plant height between the two methods of cultivation.

When the soil was maintained under permanent submersion the plant growth stopped just after the flowering stage.

Growth and development of rice plant grown in dry conditions were apparently normal, except the production of biomass that resulted quite reduced as show the data of plant height lower than standard culture. In particular, the rice plant showed more reduced and superficial roots due to the inadequate water supply and low moisture content in the upper layers of the soil. The dryland conditions, however, appeared to promote the plant growth until to the ripening stage.

In the permanent flooded pots increasing of N rate from 100 to 200 kg ha^{-1} affected generally the plant height. The application of different rates of N in dry conditions resulted in substantially insignificant differences in plant height among the treatments. These results could indicate a reduced availability of N, independently from the treatments, influenced by the nitrification and leaching of N in dryland conditions.

b] Tiller number

The effects of water management on the fertile tiller number are shown in Table 4. It should be emphasized that the fertile tiller number per surface unit was slightly reduced in dryland treatment compared with the flooded conditions. There were not substantial differences in the productive tiller number among the N treatments in both the conditions depending on the water treatment.

c] Grain yield

In the case of grain yield (at 14 % of moisture content) the results show (Table 4) that it was significantly lower in dryland conditions (7.7 t ha^{-1}) compared with the flooded pots (11.3 t ha^{-1}). The increase of N rate application did not influence yield in both cultural systems although a tendency for a marginal decrease was seen in dry condition.

B. Grain quality and N analysis

a] Head rice yield

Results from milling process on the grain samples (Table 4) showed that the dry method of cultivation did not affect negatively the head rice yield (percentage of whole or unbroken milled grain). On the contrary, the dry soil conditions resulted in an slight improvement of commercial grain quality. The maximum value of head rice yield (66.75%) was obtained from highest N treatment in dry pots. This result was very similar to those observed in field experiments with the same water treatment.

b] Grain N analysis

Total N, NO3-N and protein-N concentration and uptake by rice caryopsis (hulled grain) harvested in pot experiments are shown in Table 5. Total- and protei-N concentrations on dry matter basis was significantly higher in dry treatments than in flooded conditions. Thus, as grain yield lowered in dry treatments as total- and protein-N concentrations increased. Application of the higher N rates (N2 and N3) resulted in a significant increase of total- and protein-N concentrations in both cultural methods.

On the contrary, the concentration of grain NO3-N was significantly higher in the flooded conditions compared with the dry ones, independently of the rate of N application. It seems that the dry conditions results in a substantial reduction of NO3-N accumulation in rice caryopsis, with an important gain in rice quality from the point of view of human consumption.

The data of nitrogen forms uptake showed that total-N, NO3-N and protein-N uptakes were significantly lower under dryland condition, compared with the flood cultivation condition, independently of the rate of N application. Only in flooded pots, the treatments with N fertilizer increased the three N uptake parameters. It appear very clear that under dry cultivation the N uptake mechanism in rice is dramatically changed and affects the yield. These results could be related in part to the reduced development and activity of the root system.

Conclusions

Experiments carried out in the period 1994-1997 furnished preliminary results suggesting potential for alternative aerobic rice cultivation under non-flooded conditions. The lower amount of water supplied with the aerobic method reduced plant growth and prolonged cycle duration differently for the cultivars. Non-flooded conditions also influenced the varieties yielding response.

The major yield reduction would appear to be due to incomplete grain filling and high floret sterility. However, good performing rices may be among earlier maturing cultivars. The variability in cultivar response to water stresses from non-flooded conditions shows, in conclusion, a potential for genetic improvement.

Aerobic rice production may be adapted to non traditional rice areas where soil flooding is problematic or water cost is prohibitive.

The advantages of dry rice method include:

❑ saving water consumption
❑ economizing costs for machinery usage
❑ reducing constraints at planting time
❑ improving rice stand establishment.

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Table 1. Days to heading (DS) of 15 rice genotypes cultivated in dry soil conditions. VERCELLI (Italy)

Genotypes	1994	1995	1996	1997
PANDA	108	103	121	
UPLA 64 A	110			
KORAL	110	105	121	
DORADO X STRELLA	111			
INTA X ISC 209	114			
MARAMONTI	109			
PEGASO	103	105	115	
AGO	98			
GHIBLI		96	103	
DORELLA	106	106	123	
CRIPTO	99	104	120	
GIADA	120	114		
GRALDO	109		120	
ISC 402/2	101			
LOTO	104	102	116	
INTA X PANDA	130			
SELENIO		104	124	
DRAGO			118	
CARNAROLI			129	
ZENA			127	
ALPE				
ISC 403 X 178			105	
ICARO			111	
DEDALO		109	123	
IDRA			115	
ARTIGLIO			121	
ISC 413/419 X 242/2				
DIANA				
ELBA			121	
UPLA 64 C X 237				
OTOMEMOCHI				
PERLA			138	
KORAL X STRELLA				
Average	**108.8**	**107.14**	**121.27**	

Table 2. Days to ripening (DS) of 15 rice genotypes cultivated in dry soil conditions. VERCELLI (Italy)

Genotypes	1994	1995	1996	1997
PANDA	154	143	160	160
UPLA 64 A	153			
KORAL	160	160	161	163
DORADO X STRELLA	129			
INTA X ISC 209	160			
MARAMONTI	159			
PEGASO	153	141	163	165
AGO	151			
GHIBLI		128	142	135
DORELLA	151	156	157	162
CRIPTO	152	154	158	
GIADA	162	168		
GRALDO	154		186	
ISC 402/2	153			
LOTO	149	140	150	162
INTA X PANDA	182			
SELENIO		147	168	165
DRAGO			184	
CARNAROLI				
ZENA			173	
ALPE				163
ISC 403 X 178		164		
ICARO		162		
DEDALO		158		171
IDRA		155		
ARTIGLIO				
ISC 413/419 X 242/2				162
DIANA				167
ELBA			186	
UPLA 64 C X 237				164
OTOMEMOCHI				167
PERLA			183	166
KORAL X STRELLA				164
Average	**154.8**	**152.0**	**167.0**	**162.4**

Table 3. Yield (t ha^{-1}) of 15 rice genotypes cultivated in dry soil conditions. VERCELLI (Italy)

Genotypes	1994	1995	1996	1997
PANDA	5.99	4.48	4.00	7.13
UPLA 64 A	5.92			
KORAL	5.60	5.02	4.52	8.55
DORADO X STRELLA	5.48			
INTA X ISC 209	5.32			
MARAMONTI	5.13			
PEGASO	4.77	3.90	3.52	8.32
AGO	4.73			
GHIBLI		5.36	3.84	6.13
DORELLA	4.71	4.73	3.33	7.06
CRIPTO	4.32	4.99	3.62	
GIADA	4.13	1.13		
GRALDO	3.93		3.68	
ISC 402/2	3.84			
LOTO	3.40	5.15	3.02	7.67
INTA X PANDA	1.18	0,08		
SELENIO		5.49	1.39	7.26
DRAGO			3.13	
CARNAROLI			2.26	
ZENA			3.24	
ALPE				7.45
ISC 403 X 178		4.59		
ICARO		3.76		
DEDALO		3.61	3.32	6.63
IDRA		2.91		
ARTIGLIO		0.25		
ISC 413/419 X 242/2				6.49
DIANA				8.64
ELBA			2.56	
UPLA 64 C X 237				9.03
OTOMEMOCHI				7.30
PERLA			2.04	7.57
KORAL X STRELLA				7.78
Average	**4.56**	**3.69**	**3.16**	**7.53**

Table 4. Effects of water regime on rice culture in pot experiments (Year 1996)

Soil treatment	Days to ripening ds	Plant height at harvesting cm	Tiller number n m^{-2}	Milling rate %	Yield t ha^{-1}
Flooded					
N1 (100)	137.0	106.65	850.5	66.50	11.2
N2 (150)	138.7	108.55	899.5	65.75	11.2
N3 (200)	138.7	109.67	875.5	65.75	11.6
No flooded					
N1	142.7	87.90	746.0	66.50	8.2
N2	142.2	78.85	741.5	66.75	7.9
N3	142.2	80.65	769.5	65.75	7.0

Table 5. Nitrogen concentration and uptake in rice grain as affected by the water regime in pot experiments (Year 1996)

Soil treatment	N concentration (on dry basis)			N uptake		
	Total N %	N0 3-N (ppm)	Protein- N %	Total N (kg a^{-1})	NO 3-N (g ha^{-1})	Protein -N (kg ha^{-1})
Flooded						
N1 (100)	1.31	8.61	1.27	134.2	88.2	130.1
N2 (150)	1.37	7.17	1.34	141.4	73.7	137.7
N3 (200)	1.40	8.66	1.37	148.5	91.8	145.0
No flooded						
N1	1.50	6.17	1.44	112.8	46.8	108.3
N2	1.57	5.53	1.49	112.1	39.3	106.5
N3	1.59	4.83	1.52	101.9	31.1	97.5

Figure 1. Dry rice performance, 1994: Yield and grain moisture

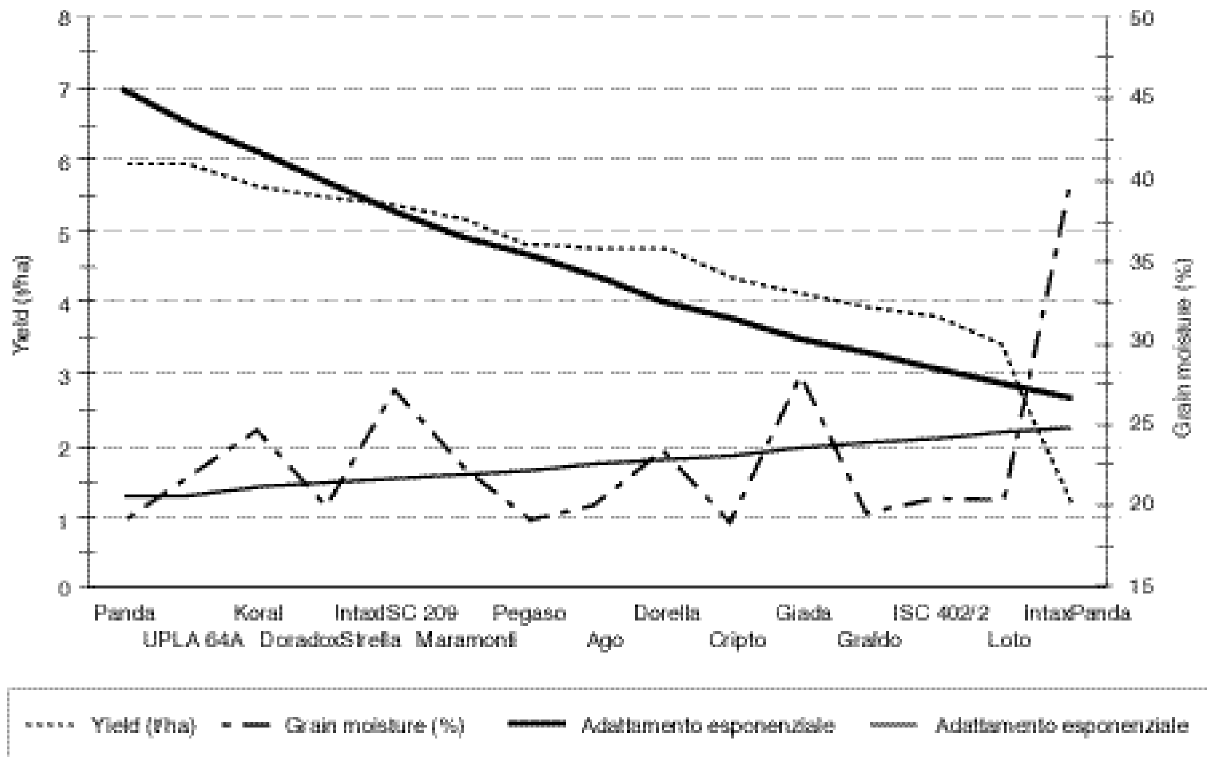

Figure 2. Dry rice performance 1994: whole grain (%)

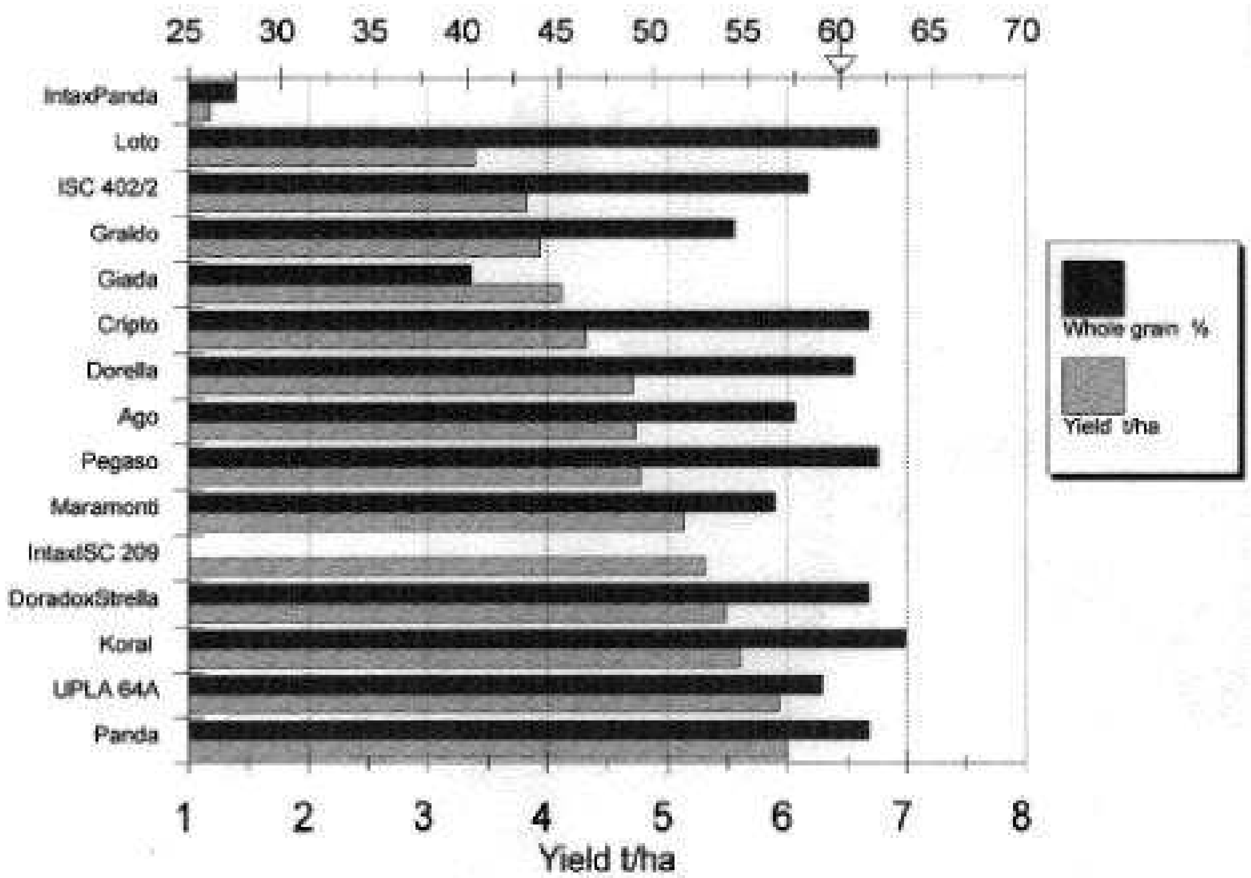

Figure 3. Dry rice performance 1994: protein content (%)

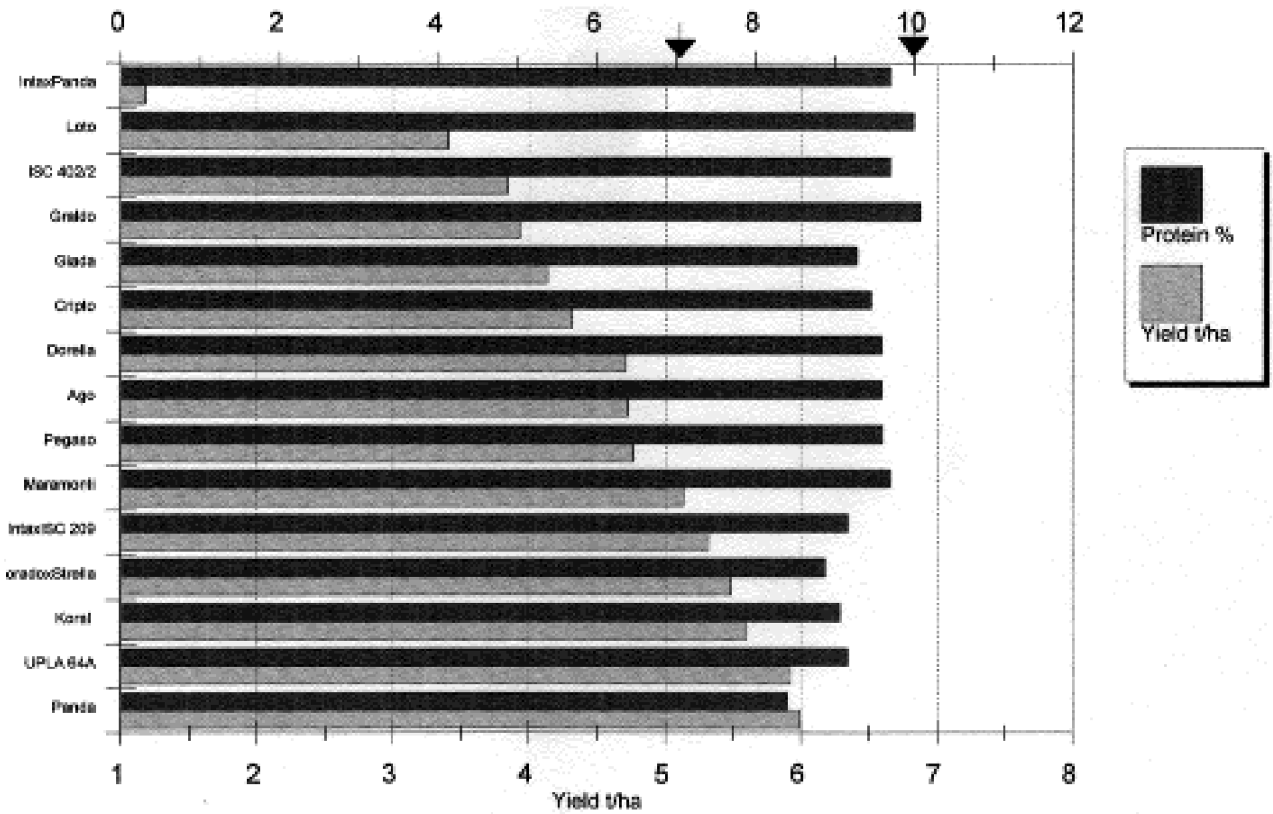

Figure 4. Dry rice performance 1994: Amylose content (%)